IMAGE PICKUP LENS

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to an image pickup lens suitable

5   for mounting in a camera which uses a CCD or CMOS device as a

pickup element.

Description of Related Art

One characteristic of this lens for mounting in a compact

camera using a CCD or CMOS device as a pickup element is a

10 short optical length. One lens of this type is for example

the pickup lens disclosed in Japanese Patent Laid-open No. 10-

206730.

However, in the pickup lens disclosed in this reference,

the distance from the aperture diaphragm plane to the second

15 surface (the image-side surface) of the second lens is 5.3 mm,

and the optical length is too long for use as a lens mounted

in a compact camera using a CCD or CMOS device as a pickup

element. In the pickup lens system disclosed in Japanese

Patent Laid-open No. 10-206730, an aperture diaphragm is

20 inserted between the first lens and the second lens. That is,

the pickup lens system disclosed in this reference employs a

construction in which only one diaphragm is provided.

It is known that the position of an aperture diaphragm

has important significance for lens design (see for example

25 Fumio Kondo, Renzu no Sekkei Gihou, Kougaku Kougyou Gijutsu

Kyoukai, 2nd edition February 1, 1983). In other words, it is

known that: (a) the entrance pupil position conjugate with

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the aperture diaphragm position is related to coma aberration,

astigmatic aberration, distortion aberration, and similar, and

is the basis for determining the third-order aberration

coefficient; (b) when an aperture diaphragm is set at the

5   position a distance t from the object-side surface (first

surface) of the first lens counting from the object side (the

first lens), measured along the optical axis moving toward the

image side, if the value of B as defined by the equation (i)

below is 0, then the basis is given for the Fraunhofer

10 condition, according to which a sufficiently small aberration

is realized;

$$B = C - St \qquad\qquad (i)$$

where C and S are constants related to the third-order

aberration coefficient; and, (c) the basis is given for the

15 Zinken-Sommer condition, according to which the closer the

value of Z as defined in equation (ii) below is to 0, the

better the aberration correction is guaranteed to be;

$$Z = St2 - 2Ct + A \qquad\qquad (ii)$$

where C, S, and A are constants related to the third-

20 order aberration coefficient.

In this way, when conducting a quantitative examination

of aberration, the position of an aperture diaphragm plays an

essential role, and is an important basic parameter of the

lens system.

25 However, a short optical length is required of an image

pickup lens for mounting in a compact camera as described

above. In addition, an image pickup lens mounted in a compact

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camera as described above must be such that distortion of the formed image is not perceived visually, and such that various aberrations are corrected to small values as required by the integration density of the pickup element.

5   In the following explanation, "various aberrations are corrected to amounts sufficiently small that distortion of the image is not recognized by visual perception, and sufficiently small as to satisfy the requirements of the integration density of the pickup element" is, for simplicity, represented

10 by the phrase "various aberrations are satisfactorily corrected" or similar. An image for which various aberrations are satisfactorily corrected may be called a "satisfactory image".

An object of this invention is to provide an image pickup

15 lens in which various aberrations are satisfactorily corrected, the optical length is short, and moreover sufficient back focus is maintained.

SUMMARY OF THE INVENTION

An image pickup lens of this invention which achieves the

20 above object is configured by arranging, in order from the object side, an aperture diaphragm S_1; a first lens L_1; a second diaphragm S_2; and a second lens L_2. The first lens L_1 has a meniscus shape with the concave surface facing the object side, and having positive refractive power. The second

25 lens L_2 has a meniscus shape with the concave surface facing the image side, and having negative refractive power.

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Further, in the image pickup lens, at least one surface of the first lens L_1 is aspherical, at least one surface of the second lens L_2 is aspherical, and overall at least two lens surfaces are aspherical; and the following conditions are

5 satisfied.

$$0.09 < |f_1/f_2| < 0.37 \qquad (1)$$

$$1.33 < |r_1/f| < 47.77 \qquad (2)$$

$$3.08 < |r_1/r_2| < 113.12 \qquad (3)$$

$$0.63 < D/f < 0.87 \qquad (4)$$

10 Here f is the focal length of the entire system (the combined focal length of the lens system comprising the first and second lenses), f_1 is the focal length of the first lens, f_2 is the focal length of the second lens, D is the distance from the aperture diaphragm plane to the second surface

15 (image-side surface) of the second lens (lens center length), r_1 is the radius of curvature of the object-side surface of the first lens L_1 in the vicinity of the optical axis (axial radius of curvature), and r_2 is the radius of curvature of the image-side surface of the first lens L_1 in the vicinity of the

20 optical axis (axial radius of curvature).

The aperture diaphragm S_1 of this invention is positioned between the object and the first lens L_1. In other words, the aperture diaphragm S_1 is set on the outside of the first lens L_1, that is, in front of the first surface (the object-side

25 surface) of the first lens. This aperture diaphragm S_1 forms an incidence plane. A second diaphragm S_2 provided between the first lens L_1 and the second lens L_2 is inserted in order to

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cut out so-called flare, which is light which strikes the peripheral edge of a lens or similar and is irregularly reflected.

Next, the significance of the above condition equations (1) through (4) is explained.

The above condition equation (1) determines the power distribution of the first lens L_1 and second lens L_2; if $|f_1/f_2|$ falls below the lower limit, the power of the first lens L_1 is stronger and the power of the second lens is weaker, so that correction of the spherical aberration, coma aberration, and distortion aberration produced by the first lens becomes difficult. And if $|f_1/f_2|$ exceeds the upper limit, the power of the first lens L_1 becomes weaker, and consequently the power of the second lens must be increased in order to shorten the combined focal length f and back focus b_f (distance from the point of intersection of the image-side surface of the second surface of the second lens with the optical axis, to the point of intersection of the light-receiving surface with the optical axis) of the lens system. Hence correction of the distortion aberration and coma aberration produced by the second lens L_2 becomes difficult. As a result, if $|f_1/f_2|$ falls below the lower limit or rises above the upper limit, a satisfactory image cannot be obtained. Consequently using an image pickup lens of this invention which satisfies the condition equation (1), a satisfactory image can be obtained.

The above condition equation (2) sets the range for the value of $|r_1/f|$ when the radius of curvature r_1 on the object

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side of the first lens L_1 is normalized by the combined focal

length f for the pickup lens system. If $|r_1/f|$ falls below the

lower limit, coma aberration increases, and if an attempt is

made to correct this, distortion aberration results. Hence

5 the need arises for means to cut rays which pass through the

peripheral portions of lenses, and as a result the image is

darker.

On the other hand, if $|r_1/f|$ exceeds the upper limit,

astigmatic aberration and coma aberration are increased, and

10 moreover the lens thickness is increased, so that a

satisfactory image cannot be obtained over a broad angle range.

That is, if the radius of curvature r_1 on the object side of

the first lens L_1 is set so as to satisfy condition equation

(2), it becomes easy to correct the coma aberration,

15 astigmatic aberration and distortion aberration of the pickup

lens, the pickup lens can be made more compact while

maintaining broad angles, and in addition image brightness can

be preserved.

The above condition equation (3) stipulates the ratio of

20 the radii of curvature r_1 and r_2 of the first lens L_1; if

$|r_1/r_2|$ falls below the lower limit, the optical length

increases, or the lens diameter increases, or distortion

aberration is increased. On the other hand, if $|r_1/r_2|$ rises

above the upper limit, coma aberration increases. In other

25 words, if calculations are performed so as to satisfy

condition equation (3), correction of the coma aberration and

distortion aberration of the pickup lens becomes easy, and moreover the pick lens can be made more compact.

The above condition equation (4) stipulates the range for the value obtained by normalizing the distance D from the point of intersection of the aperture diaphragm S_1 with the optical axis to the point of intersection of the second surface (image-side surface) of the second lens with the optical axis by the combined focal length f for the lens system. When this lens system is actually used, cover glass or similar is inserted behind (on the image side of) the second lens L_2. The value of D/f provides an indicator of the magnitude of the optical length (the distance from the incidence aperture position to the imaging plane) of the entire image pickup lens of this invention, with the cover glass or other optical component added. By keeping this value within the range of the condition equation (4), the optical length as calculated assuming the use of cover glass or similar can be kept to a length within the range allowable for practical application.

As is clear from the first embodiment through the fourth embodiment described below, the four conditions stipulated by the condition equations (1) through (4) make possible the realization of an image pickup lens in which various aberrations are satisfactorily corrected, which has an optical length of 6 mm or less (D value of 2.98 mm or less), and which affords excellent productivity.

Looking again at the pickup lens system disclosed in

Japanese Patent Laid-open No. 10-206730, as has already been

explained, an aperture diaphragm is set between the first lens

and the second lens. On the other hand, in this invention the

5   aperture diaphragm position is in front of the first lens. As

a result, the manner in which various aberrations appear is

clearly different for this invention and for the pickup lens

system disclosed in Japanese Patent Laid-open No. 10-206730,

and the lens system disclosed in the above reference can be

10   understood to be structurally different from the lens system

of this invention.

Further, it is preferable that in an image pickup lens of

this invention, all component lenses be formed from plastic

material (a polymer material which can be molded and shaped by

15   plastic deformation under the application of heat or pressure,

or both, and which is transparent to visible light).

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages

of the present invention will be better understood from the

20   following description taken in connection with the

accompanying drawings, in which:

Fig. 1 is a summary cross-sectional view to explain the

configuration of an image pickup lens of this invention;

Fig. 2 is a summary cross-sectional view to explain a

25   first embodiment of an image pickup lens of this invention;

Fig. 3 is a graph of distortion aberration of the image

pickup lens of Fig. 2;

Fig. 4 is a graph of astigmatic aberration of the image pickup lens of Fig. 2;

Fig. 5 is a graph of chromatic/spherical aberration of the image pickup lens of Fig. 2;

5　　　　Fig. 6 is a summary cross-sectional view to explain a second embodiment of an image pickup lens of this invention;

Fig. 7 is a graph of distortion aberration of the image pickup lens of Fig. 6;

Fig. 8 is a graph of astigmatic aberration of the image

10　pickup lens of Fig. 6;

Fig. 9 is a graph of chromatic/spherical aberration of the image pickup lens of Fig. 6;

Fig. 10 is a summary cross-sectional view to explain a third embodiment of an image pickup lens of this invention;

15　　　　Fig. 11 is a graph of distortion aberration of the image pickup lens of Fig. 10;

Fig. 12 is a graph of astigmatic aberration of the image pickup lens of Fig. 10;

Fig. 13 is a graph of chromatic/spherical aberration of

20　the image pickup lens of Fig. 10;

Fig. 14 is a summary cross-sectional view to explain a fourth embodiment of an image pickup lens of this invention;

Fig. 15 is a graph of distortion aberration of the image pickup lens of Fig. 14;

25　　　　Fig. 16 is a graph of astigmatic aberration of the image pickup lens of Fig. 14; and,

Fig. 17 is a graph of chromatic/spherical aberration of the image pickup lens of Fig. 14.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Below, aspects of this invention are explained, referring to the drawings. These drawings merely show in summary the shapes, sizes, and positional relations of components to an extent enabling an understanding of this invention, and the numerical and other conditions explained below are merely suitable examples; the present invention is not limited only to the aspects of the invention.

Embodiments

Fig. 1 is a drawing of the configuration of an image pickup lens of this invention. The first and second lenses, counting in order from the object side toward the image side, are indicated respectively by L_1 and L_2. The pickup surface (light-receiving surface of the solid-state pickup element) is represented by 10; the cover glass separating the pickup surface and the lens system is represented by 12; the two planes comprised by the second diaphragm S_2 are represented by 14 and 16, in order respectively from the image side to the object side; and the plane of the diaphragm comprised by the aperture diaphragm S_1 is represented by 18.

The parameters r_i (i=1, 2, 3, ..., 9) and d_i (i=1, 2, 3, ..., 9) and other parameters shown in this drawing are assigned specific numerical values in Table 1 through Table 4 below. The subscripts i=1, 2, ..., 9 are assigned to correspond to lens surface numbers, or to lens thicknesses or

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intervals between lenses, in order from the object side toward the image side. That is, r_i is the radius of curvature of the ith surface (for an aspherical surface, the radius of curvature at the axis); d_i is the distance from the ith surface

5   to the i+1th surface; N_i is the refractivity of the lens media from the ith surface to the i+1th surface; and, v_i is the dispersion of the lens media from the ith surface to the i+1th surface.

The optical length is the value obtained by adding d_1 to

10   d_9.

The back focus b_f is $d_7 + d_8 + d_9$.

Also, $D = d_1 + d_2 + d_3 + d_4 + d_5 + d_6$.

Aspherical data is shown, together with surface numbers, in the right-hand columns of Table 1 through Table 4. Because

15   the surfaces in question are flat planes, the values of the radii of curvature r_3 and r_4 of the second diaphragm S_2 and r_7 and r_8 of the cover glass are indicated by ∞.

An aspherical surface used in this invention is represented by the following equation.

20   $Z = ch^2/[1 + [1 - (1+k)c^2h^2] + 1/2] + A_0h^4 + B_0h^6 + C_0h^8 + D_0h^{10}$

Here Z is the depth from the plane which is tangential at the lens vertex, c is the curvature of the surface in the vicinity of the optical axis, h is the height from the optical axis, k is the conic constant, A_0 is the fourth-order aspheric

25   coefficient, B_0 is the sixth-order aspheric coefficient, C_0 is the eighth-order aspheric coefficient, and D_0 is the tenth-order aspheric coefficient.

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In each of Table 1 through Table 4 in this Specification, in representations of numerical values indicating aspheric coefficients, "e-1" means "10^{-1}". Moreover, a value shown as a focal length f is the combined focal length of the lens system

5   comprising the first and second lenses.

The first through fourth embodiments are explained below, referring to Fig. 2 through Fig. 17.

Fig. 2, Fig. 6, Fig. 10, and Fig. 14 show summary cross-sectional views of lens configurations and spot diagrams, and

10   indicate the degree of spreading of a point image on the image plane with respect to the distance of incidence. In these drawings, the spot images are drawn surrounded by a rectangle on the right side of the pickup plane 10 (light-receiving surface of the solid-state pickup element) which is long in

15   the vertical direction, showing the extent of spreading of the point image projected on the pickup plane 10 to correspond to the size of a circle. Distortion aberration curves are shown in Fig. 3, Fig. 7, Fig. 11 and Fig. 15, astigmatic aberration curves in Fig. 4, Fig. 8, Fig. 12 and Fig. 16, and

20   chromatic/spherical aberration in Fig. 5, Fig. 9, Fig. 13 and Fig. 17.

A distortion aberration curve shows the aberration amount (the amount by which the tangent condition is not satisfied, expressed as a percentage along the horizontal axis) versus

25   the distance from the optical axis (expressed as a percentage along the vertical axis, with the maximum distance from the optical axis within the image plane equal to 100). An

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astigmatic aberration curve shows the amount of aberration along the horizontal axis (in mm units) for a distance from the optical axis, similarly to a distortion aberration curve. Astigmatism was represented as aberration amounts (in mm

5   units) in the meridional plane and in the sagittal plane. A chromatic/spherical aberration curve shows the amount of aberration along the horizontal axis (in mm units) for a distance of incidence h (F number). In a chromatic/spherical aberration curve, aberration amounts are shown for the C line

10   (light of wavelength 656.3 nm), the d line (light of wavelength 587.6 nm), the e line (light of wavelength 546.1 nm), the F line (light of wavelength 486.1 nm), and the g line (light of wavelength 435.8 nm). The refractivity is the refractivity for the d line (light of wavelength 587.6 nm).

15   Below, the radii of curvature of component lenses (mm units), intervals between lens surfaces (mm units), refractivity of lens materials, Abbe number of lens materials, focal length, numerical apertures, and aspheric coefficients are listed for the first embodiment (Table 1), second

20   embodiment (Table 2), third embodiment (Table 3), and fourth embodiment (Table 4).

Table 1

First Embodiment

Radius of Curvature (r_i)	Distance (d_i)	Refractivity (N_i)	Abbe Number (ν_i)	Aspheric Coefficient				
				k	A_0	B_0	C_0	D_0
$r_1 = -15.3122$	$d_1 = 0.1300$			0.3088e+3	-0.2737e-1	0.1308e0	-0.6038e0	0.5411e0
$r_2 = -1.5519$	$d_2 = 1.6000$	$N_2 = 1.53$	$\nu_2 = 56.0$	1.740e0	0.2747e-1	-0.4643e-1	0.6315e-1	-0.2187e-1
$r_3 = \infty$	$d_3 = 0$							
$r_4 = \infty$	$d_4 = 0.0500$							
$r_5 = 3.5240$	$d_5 = 0.2500$			0.1183e+1	-0.2305e-1	0.9359e-2	-0.1240e-2	-0.9924e-4
$r_6 = 2.3577$	$d_6 = 0.800$	$N_6 = 1.53$	$\nu_6 = 56.0$	0.2350e0	0.1247e-1	-0.3995e-1	0.2641e-1	-0.5894e-2
$r_7 = \infty$	$d_7 = 0.800$							
$r_8 = \infty$	$d_8 = 1.0500$	$N_8 = 1.52$	Cover Glass					
$r_9 = \infty$	$d_9 = 0.8145$							

Focal Length f = 3.296 mm
Numerical Aperture Fno = 2.80

Table 2

Second Embodiment

Radius of Curvature (r_i)	Distance (d_i)	Refractivity (N_i)	Abbe Number (ν_i)	Aspheric Coefficient				
				k	A_0	B_0	C_0	D_0
r_1 = -4.9982	d_1 = 0.1000			0.2088e+2	-0.2700e-1	-0.8479e-2	-0.1668e0	0.1490e0
r_2 = -1.6179	d_2 = 1.3000	N_2 = 1.53	ν_2 = 56.0	0.1066e0	-0.2228e-1	0.7325e-2	-0.3840e-2	-0.1272e-2
r_3 = ∞	d_3 = 0							
r_4 = ∞	d_4 = 0.0500							
r_5 = 2.0396	d_5 = 0.1500			0.6279e-1	-0.3664e-1	0.2669e-2	-0.3176e-2	0.1428e-2
r_6 = 1.6019	d_6 = 0.8000	N_6 = 1.53	ν_6 = 56.0	-0.2613e0	0.2194e-1	-0.7339e-1	0.4147e-1	-0.8256e-2
r_7 = ∞	d_7 = 0.9630							
r_8 = ∞	d_8 = 1.0500	N_8 = 1.52	Cover Glass					
r_9 = ∞	d_9 = 1.2159							

Focal Length f = 3.74 mm
Numerical Aperture = 2.80

Table 3

Third Embodiment

Radius of Curvature (r_i)	Distance (d_i)	Refractivity (N_i)	Abbe Number ν_i	Aspheric Coefficient				
				k	A_0	B_0	C_0	D_0
$r_1 = -10.1892$	$d_1 = 0.0850$			0.3485e+2	-0.4651e-1	0.2140e-1	-0.9504e-1	0.5164e-1
$r_2 = -1.7455$	$d_2 = 1.6000$	$N_2 = 1.53$	$\nu_2 = 56.0$	-0.5254e-1	-0.1206e-1	0.8422e-2	-0.3085e-2	-0.9854e-3
$r_3 = \infty$	$d_3 = 0$							
$r_4 = \infty$	$d_4 = 0.0500$							
$r_5 = 2.2687$	$d_5 = 0.2500$			0.1914e0	-0.3215e-1	0.7814e-2	-0.3069e-2	0.1297e-3
$r_6 = 1.5926$	$d_6 = 0.7800$	$N_6 = 1.53$	$\nu_6 = 56.0$	-0.4005e0	0.7101e-2	-0.4901e-1	0.3515e-1	-0.9398e-2
$r_7 = \infty$	$d_7 = 1.1306$							
$r_8 = \infty$	$d_8 = 1.0500$	$N_8 = 1.52$	Cover Glass					
$r_9 = \infty$	$d_9 = 1.0000$							

Focal Length f = 3.912 mm
Numerical Aperture Fno = 2.80

Table 4

Fourth Embodiment

Radius of Curvature (r_i)	Distance (d_i)	Refractivity (N_i)	Abbe Number (ν_i)	Aspheric Coefficient				
				k	A_0	B_0	C_0	D_0
r_1 = -167.0550	d_1 = 0.0750			0.6585e+2	-0.6152e-1	-0.1515e-1	-0.1136e0	0.4456e-1
r_2 = -1.4769	d_2 = 1.4000	N_2 = 1.53	ν_2 = 56.0	-0.9126e-1	-0.1475e-1	0.6474e-2	-0.3766e-2	-0.2370e-2
r_3 = ∞	d_3 = 0							
r_4 = ∞	d_4 = 0.0500							
r_5 = 3.3843	d_5 = 0			0.7694e-1	-0.2977e-1	-0.6861e-2	-0.9187e-3	0.3984e-2
r_6 = 1.7058	d_6 = 0.7800	N_6 = 1.53	ν_6 = 56.0	-0.4174e0	0.1363e-1	-0.6230e-1	0.3515e-1	-0.5201e-2
r_7 = ∞	d_7 = 0.8000							
r_8 = ∞	d_8 = 0.7000	N_8 = 1.493	Cover Glass					
r_9 = ∞	d_9 = 1.2658							

Focal Length f = 3.498 mm

Numerical Aperture Fno = 2.80

Below, the characteristics of each of the embodiments are

discussed.

In all of the first through the fourth embodiments,

ZEONEX E48R (ZEONEX is a registered trademark, and E48R is a

5   product number, of Nippon Zeon Co., Ltd.), which is a

cycloolefin plastic, was employed in the first lens (L_1), which

has a meniscus shape with the concave surface facing the

object side and with positive refractive power, and in the

second lens (L_2), which has a meniscus shape with the concave

10   surface facing the image side and with negative refractive

power.

Both surfaces of the first lens (L_1) and both surfaces of

the second lens (L_2) are aspherical. That is, the number of

aspherical surfaces is four in each of the embodiments.

15   The Abbe number of the ZEONEX E48R which is the material

of the first lens (L_1) and second lens (L_2) is 56; from

simulation results it was found that if the Abbe number of the

material of these lenses is in the range from 45 to 65, no

practical difference occurs in the aberration or other lens

20   performance. It was found that if the Abbe number is within

the above range of values, a pickup lens can be realized which

satisfies objects of this invention, which are satisfactory

correction of various aberrations of the pickup lens compared

with the various aberrations of a pickup lens of the prior art,

25   and an optical length of 6 mm or less.

In the first embodiment, second embodiment, and third

embodiment, cover glass of thickness 1.05 mm is inserted

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between the lens system and the pickup surface; in the fourth embodiment, 0.70 mm cover glass is inserted. The material of the cover glass is, in the three examples of the first through the third embodiments, glass material of refractivity 1.52, and in the fourth embodiment, acrylic resin material of refractivity 1.493. The various aberrations explained below are calculated assuming the existence of these cover glasses. That is, the cover glasses comprise the r_7 and r_8 surfaces, and the parameter d_8 representing the thickness is, for the three examples of the first through third embodiments, $d_8=1.05$ mm, and for the fourth embodiment, $d_8=0.70$ mm.

First Embodiment

(A) The focal length for the entire system is f = 3.296 mm.

(B) The focal length of the first lens is f_1 = 3.13 mm.

(C) The focal length of the second lens is f_2 = -17.63 mm.

(D) The radius of curvature of the object-side surface of the first lens is r_1 = -15.3122 mm.

(E) The radius of curvature of the image-side surface of the first lens is r_2 = -1.5519 mm.

(F) The distance from the aperture diaphragm position to the second surface of the second lens is D = 2.83 mm.

Hence:

(1) $|f_1 / f_2| = |3.13/-17.63|$　　　　= 0.1775 ≒ 0.18

(2) $|r_1 / f| = |-15.3122/3.296|$　　= 4.646 ≒ 4.65

(3) $|r_1 / r_2| = |-15.3122/-1.5519|$ = 9.867 ≒ 9.87

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(4) $D/f = 2.83/3.296 = 0.8586 \fallingdotseq 0.86$

Therefore the lens system of the first embodiment satisfies all of the following condition equations (1) through (4).

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$$0.09 < |f_1/f_2| < 0.37 \qquad (1)$$
$$1.33 < |r_1/f| < 47.77 \qquad (2)$$
$$3.08 < |r_1/r_2| < 113.12 \qquad (3)$$
$$0.63 < D/f < 0.87 \qquad (4)$$

Below, "condition equations" refers to the above four
10 condition equations (1) through (4).

The aperture diaphragm S_1 is as indicated in Table 1, and is provided at a position 0.13 mm ($d_1=0.13$ mm) in front of the first surface of the first lens (the object-side surface). The numerical aperture (F number) is 2.8, and the combined
15 focal length f is 3.296 mm.

Fig. 2 shows the results of ray tracing, and a spot diagram showing the spreading of a point image on the pickup surface. It is seen that there is some spreading of the point image P only very close to the peripheral portion, and that a
20 satisfactory point image is obtained over nearly the entirety of the pickup surface.

The optical length is 5.495 mm, which is within 6 mm, and a sufficient back focus of 2.665 mm is also secured.

Graphs are shown of the distortion aberration curve 20 in
25 Fig. 3, astigmatic aberration curves (aberration curve 22 for the meridional plane and aberration curve 24 for the sagittal plane) in Fig. 4, and chromatic/spherical aberration curves

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(aberration curve 26 for the C line, aberration curve 28 for the d line, aberration curve 30 for the e line, aberration curve 32 for the F line, and aberration curve 34 for the g line) in Fig. 5. The vertical axes of the aberration curves

5   of Fig. 3 and Fig. 4 show the image height, with 100%, 85%, 80%, 70%, 50%, and 30% corresponding respectively to 2.3 mm, 1.9 mm, 1.8 mm, 1.6 mm, 1.1 mm, and 0.68 mm. In the first embodiment, an image height of 2.3 mm when converted into an angle made by the chief ray with the optical axis before

10   incidence on the lens system corresponds to 36°. The vertical axis of the aberration curve of Fig. 5 shows the distance of incidence h (F number); the maximum is F2.8. The horizontal axis indicates the magnitude of aberration.

At an image height of 100% (image height 2.3 mm), the

15   absolute value of the distortion aberration is a maximum of 3.9%, and in the range below an image height of 2.3 mm, the absolute value is less than 3.9%.

At an image height of 100% (image height 2.3 mm), the absolute value of the astigmatic aberration is a maximum of

20   0.14 mm in the sagittal plane, and in the range below an image height of 2.3 mm, the absolute value is not more than than 0.14 mm.

The absolute value of the chromatic/spherical aberration for the g line at the optical axis is a maximum of 0.18 mm,

25   and the absolute value of the aberration is within 0.18 mm.

Second Embodiment

(A) The focal length for the entire system is f = 3.74 mm.

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(B) The focal length of the first lens is $f_1 = 3.98$ mm.

(C) The focal length of the second lens is $f_2 = -38.38$ mm.

(D) The radius of curvature of the object-side surface of the first lens is $r_1 = -4.9982$ mm.

(E) The radius of curvature of the image-side surface of the first lens is $r_2 = -1.6179$ mm.

(F) The distance from the aperture diaphragm position to the second surface of the second lens is $D = 2.40$ mm.

Hence:

(1) $|f_1 / f_2| = |3.98/-38.38| \quad = 0.104 \fallingdotseq 0.10$

(2) $|r_1 / f| = |-4.9982/3.74| \quad = 1.336 \fallingdotseq 1.34$

(3) $|r_1 / r_2| = |-4.9982/-1.6179| = 3.089 \fallingdotseq 3.09$

(4) $D/f = 2.40/3.74 \quad = 0.6417 \fallingdotseq 0.64$

Therefore the lens system of the second embodiment satisfies all of the following condition equations (1) through (4).

$$0.09 < |f_1/f_2| < 0.37 \qquad\qquad (1)$$
$$1.33 < |r_1/f| < 47.77 \qquad\qquad (2)$$
$$3.08 < |r_1/r_2| < 113.12 \qquad\qquad (3)$$
$$0.63 < D/f < 0.87 \qquad\qquad (4)$$

As indicated in Table 2, the aperture diaphragm S_1 is provided at a position 0.10 mm ($d_1=0.10$ mm) in front of the first surface (object-side surface) of the first lens. The numerical aperture (F number) is 2.8, and the combined focal length f is 3.740 mm.

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Fig. 6 shows the results of ray tracing, and a spot diagram showing the spreading of a point image on the pickup surface. It is seen that there is some spreading of the point image P only very close to the peripheral portion, and that a

5 satisfactory point image is obtained over nearly the entirety of the pickup surface.

The optical length is 5.629 mm, which is within 6 mm, and a sufficient back focus of 3.229 mm is also secured.

Graphs are shown of the distortion aberration curve 36 in

10 Fig. 7, astigmatic aberration curves (aberration curve 38 for the meridional plane and aberration curve 40 for the sagittal plane) in Fig. 8, and chromatic/spherical aberration curves (aberration curve 42 for the C line, aberration curve 44 for the d line, aberration curve 46 for the e line, aberration

15 curve 48 for the F line, and aberration curve 50 for the g line) in Fig. 9. The vertical axes of the aberration curves of Fig. 7 and Fig. 8 show the image height, with 100%, 85%, 80%, 70%, 50%, and 30% corresponding respectively to 2.3 mm, 1.9 mm, 1.8 mm, 1.6 mm, 1.1 mm, and 0.68 mm. In the second

20 embodiment, an image height of 2.3 mm when converted into an angle made by the chief ray with the optical axis before incidence on the lens system corresponds to 32°. The horizontal axis indicates the magnitude of aberration. The vertical axis of the aberration curve of Fig. 9 shows the

25 distance of incidence h (F number); the maximum is F2.8.

At an image height of 80% (image height 1.8 mm), the absolute value of the distortion aberration is a maximum of

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0.6%, and in the range below an image height of 2.3 mm, the absolute value is within 0.6%.

At an image height of 100% (image height 2.3 mm), the absolute value of the astigmatic aberration is a maximum of 0.17 mm in the meridional plane, and in the range below an image height of 2.3 mm, the absolute value is not more than 0.17 mm.

The absolute value of the chromatic/spherical aberration for the g line at the optical axis is a maximum of 0.15 mm, and the absolute value of the aberration is within 0.15 mm.

Third Embodiment

(A) The focal length for the entire system is $f = 3.912$ mm.

(B) The focal length of the first lens is $f_1 = 3.73$ mm.

(C) The focal length of the second lens is $f_2 = -16.80$ mm.

(D) The radius of curvature of the object-side surface of the first lens is $r_1 = -10.1892$ mm.

(E) The radius of curvature of the image-side surface of the first lens is $r_2 = -1.7455$ mm.

(F) The distance from the aperture diaphragm position to the second surface of the second lens is $D = 2.765$ mm.

Hence:

(1) $|f_1 / f_2| = |3.73/-16.80|$ $= 0.222 \doteqdot 0.22$

(2) $|r_1 / f| = |-10.1892/3.912|$ $= 2.605 \doteqdot 2.61$

(3) $|r_1 / r_2| = |-10.1892/-1.7455| = 5.8374 \doteqdot 5.84$

(4) $D/f = 2.765/3.912$ $= 0.7068 \doteqdot 0.71$

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Therefore the lens system of the third embodiment

satisfies all of the following condition equations (1) through

(4):

$$0.09 < |f_1/f_2| < 0.37 \qquad (1)$$

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$$1.33 < |r_1/f| < 47.77 \qquad (2)$$

$$3.08 < |r_1/r_2| < 113.12 \qquad (3)$$

$$0.63 < D/f < 0.87 \qquad (4)$$

As indicated in Table 3, the aperture diaphragm S_1 is

provided at a position 0.085 mm (d_1=0.085 mm) in front of the

10 first surface (object-side surface) of the first lens. The

numerical aperture (F number) is 2.8, and the combined focal

length f is 3.912 mm.

Fig. 10 shows the results of ray tracing, and a spot

diagram showing the spreading of a point image on the pickup

15 surface. It is seen that there is some spreading of the point

image P only very close to the peripheral portion, and that a

satisfactory point image is obtained over nearly the entirety

of the pickup surface. The optical length is 5.946 mm, which

is within 6 mm, and a sufficient back focus of 3.181 mm is

20 also secured.

Graphs are shown of the distortion aberration curve 52 in

Fig. 11, astigmatic aberration curves (aberration curve 54 for

the meridional plane and aberration curve 56 for the sagittal

plane) in Fig. 12, and chromatic/spherical aberration curves

25 (aberration curve 58 for the C line, aberration curve 60 for

the d line, aberration curve 62 for the e line, aberration

curve 64 for the F line, and aberration curve 66 for the g

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line) in Fig. 13. The vertical axes of the aberration curves of Fig. 11 and Fig. 12 show the image height, with 100%, 85%, 80%, 70%, 50%, and 30% corresponding respectively to 2.3 mm, 1.9 mm, 1.8 mm, 1.6 mm, 1.1 mm, and 0.68 mm. In the third

5   embodiment, an image height of 2.3 mm when converted into an angle made by the chief ray with the optical axis before incidence on the lens system corresponds to 30°. The vertical axis of the aberration curve of Fig. 13 shows the distance of incidence h (F number); the maximum is F2.8. The horizontal

10   axis indicates the magnitude of aberration.

At an image height of 100% (image height 2.3 mm), the absolute value of the distortion aberration is a maximum of 1.5%, and in the range below an image height of 2.3 mm, the absolute value is within 1.5%.

15   At an image height of 100% (image height 2.3 mm), the absolute value of the astigmatic aberration is a maximum of 0.08 mm in the sagittal plane, and in the range below an image height of 2.3 mm, the absolute value is not more than than 0.08 mm.

20   The absolute value of the chromatic/spherical aberration for the g line at the optical axis is a maximum of 0.10 mm, and the absolute value of the aberration is within 0.10 mm.

Fourth Embodiment

(A) The focal length for the entire system is f = 3.498

25   mm.

(B) The focal length of the first lens is f_1 = 2.80 mm.

(C) The focal length of the second lens is f_2 = -7.73 mm.

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(D) The radius of curvature of the object-side surface of the first lens is $r_1 = -167.055$ mm.

(E) The radius of curvature of the image-side surface of the first lens is $r_2 = -1.4769$ mm.

(F) The distance from the aperture diaphragm position to the second surface of the second lens is $D = 2.305$ mm.

Hence:

(1) $|f_1 / f_2| = |2.80/-7.73|$ $= 0.362 \doteqdot 0.36$

(2) $|r_1 / f| = |-167.055/3.498|$ $= 47.757 \doteqdot 47.76$

(3) $|r_1 / r_2| = |-167.055/-1.4769| = 113.112 \doteqdot 113.11$

(4) $D/f = 2.305/3.498$ $= 0.6589 \doteqdot 0.66$

Therefore the lens system of the fourth embodiment satisfies all of the following condition equations (1) through (4).

$$0.09 < |f_1/f_2| < 0.37 \qquad\qquad (1)$$

$$1.33 < |r_1/f| < 47.77 \qquad\qquad (2)$$

$$3.08 < |r_1/r_2| < 113.12 \qquad\qquad (3)$$

$$0.63 < D/f < 0.87 \qquad\qquad (4)$$

As indicated in Table 4, the aperture diaphragm S_1 is provided at a position 0.075 mm ($d_1 = 0.075$ mm) in front of the first surface (object-side surface) of the first lens. The numerical aperture (F number) is 2.8, and the combined focal length f is 3.498 mm.

Fig. 14 shows the results of ray tracing, and a spot diagram showing the spreading of a point image on the pickup

surface. It is seen that there is some spreading of the point image P only very close to the peripheral portion, and that a satisfactory point image is obtained over nearly the entirety of the pickup surface. The optical length is 5.071 mm, which

5   is within 6 mm, and a sufficient back focus of 2.766 mm is also secured.

Graphs are shown of the distortion aberration curve 68 in Fig. 15, astigmatic aberration curves (aberration curve 70 for the meridional plane and aberration curve 72 for the sagittal

10   plane) in Fig. 16, and chromatic/spherical aberration curves (aberration curve 74 for the C line, aberration curve 76 for the d line, aberration curve 78 for the e line, aberration curve 80 for the F line, and aberration curve 82 for the g line) in Fig. 17. The vertical axes of the aberration curves

15   of Fig. 15 and Fig. 16 show the image height, with 100%, 85%, 70%, 50%, and 30% corresponding respectively to 2.3 mm, 1.9 mm, 1.6 mm, 1.1 mm, and 0.68 mm. In the fourth embodiment, an image height of 2.3 mm when converted into an angle made by the chief ray with the optical axis before incidence on the

20   lens system corresponds to 32°. The vertical axis of the aberration curve of Fig. 17 shows the distance of incidence h (F number); the maximum is F2.8. The horizontal axis indicates the magnitude of aberration.

At an image height of 100% (image height 2.3 mm), the

25   absolute value of the distortion aberration is a maximum of 3.2%, and in the range below an image height of 2.3 mm, the absolute value is within 3.2%.

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At an image height of 100% (image height 2.3 mm), the absolute value of the astigmatic aberration is a maximum of 0.22 mm in the meridional plane, and in the range below an image height of 2.3 mm, the absolute value is not more than 0.22 mm.

The absolute value of the chromatic/spherical aberration for the g line at the optical axis is a maximum of 0.17 mm, and the absolute value of the aberration is within 0.17 mm.

It was found that the lenses for image pickup of all of the above embodiments have the performance required of a lens for mounting in a compact camera which uses a CCD or CMOS device as a pickup element.

Thus as is clear from the above explanations of lenses for image pickup of this invention, by designing the configuration of an image pickup lens such that the condition equations (1) through (4) are satisfied, the problems to be solved by this invention are solved. That is, an image pickup lens is obtained in which various aberrations are satisfactorily corrected, a sufficient back focus is obtained, and a short optical length is maintained.

In the above-described embodiments, ZEONEX E48R plastic was used in the first and second lenses; but in addition to a plastic material other than that of the embodiments, a material other than plastic such as glass can of course also be used, so long as the various conditions explained in the embodiments are satisfied.

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As explained above, this invention enables the realization of a pickup lens suitable for use in a compact CCD camera, which can make aggressive use of plastic lenses, in which various aberrations are satisfactorily corrected, and which has an optical length of 6 mm or less.

Moreover, by means of an image pickup lens of this invention, an adequate back focus can be secured, despite the short optical length.

As explained above, in addition to use as a lens for a video camera incorporated into a portable telephone, a pickup lens of this invention is suitable for use as the lens of a video camera incorporated into a PDA (personal digital assistant), as the lens of a video camera incorporated into a toy comprising image recognition functions, and as the lens of monitoring video cameras and security video cameras.